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How Damage To Balsam Fir Develops After A Spruce Budworm Epidemic

Choristoneura
fumiferana (Clem.)

by

Thomas F. McLintock

United States Department of Agriculture • Forest Service

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by

Thomas F. McLintock[1]

Forester

Northeastern Forest Experiment Station
Forest Service, U.S. Dept. Agriculture

THE PROBLEM AHEAD

FROM 1948 TO 1952 A LIGHT to medium spruce budworm infestation occurred in the spruce-fir forests of northern Maine. During this period both the degree of infestation and the acreage affected fluctuated considerably, but the population remained below the damage level. In 1953 there was a general reduction in budworm population in all portions of northern Maine except a relatively small area of some 20,000 acres near Madawaska Lake. Here a marked increase in infestation occurred. Because of possible damage to trees on this area and the hazard of spread to adjacent areas, this tract was sprayed in the spring of 1954. Meanwhile a very severe outbreak over an area of several thousand square miles in the nearby Province of New Brunswick has become a serious threat to the spruce-fir forests of Maine.

In the face of such an insect attack the need has become acute for more information on the nature and extent of damage likely to occur. If a severe epidemic occurs, forest

[1] STATIONED AT THE EXPERIMENT STATION'S PENOBSCOT RESEARCH CENTER, BANGOR, ME.

managers will be faced with a salvage job of tremendous size. The critical question will be: How long after the first serious defoliation can fir trees be salvaged?

Future management plans will have to provide for stands severely depleted of their fir components. Since the growth rate of surviving fir will probably be reduced sharply, the extent and duration of this effect must be taken into account. While spruce and fir trees amounting to 25 to 30 million cords of wood were killed in Maine after the 1909-19 outbreak, a substantial nucleus of timber must have been left from which the present stands developed. But one can only conjecture why some stands were wiped out and others survived.

The relationship between tree characteristics and probable damage by the budworm is of considerable significance now because the practice of tree marking is gradually increasing. If it can be definitely shown that some types of trees are less likely to be killed by defoliation than others, fir stands could be marked for cutting with assurance that the residual growing stock would be considerably more resistant to death from the ravages of the budworm.

A STUDY OF BUDWORM DAMAGE

The Northeastern Forest Experiment Station, in cooperation with the Canadian International Paper Company, made a study of budworm damage in the midst of a heavy outbreak in southwestern Quebec. In 1945 experimental areas were located and initial measurements and observations were made. Permanent plots were laid out for detailed examination of trees and stand conditions in the Lake Larouche area in 1948. Observations have been repeated every year through 1952 by the Experiment Station staff.[2]

The area selected lies in the Upper Gatineau River drainage, 180 miles north of Ottawa in the district around Forbes Depot. The stands in this section had been under attack by the budworm since 1944, and possibly since 1943. In 1945 virtually 100 percent of the current year's foliage

[2] THE ASSISTANCE AND COOPERATION OF THE CANADIAN INTERNATIONAL PAPER COMPANY ARE GRATEFULLY ACKNOWLEDGED. WITHOUT THEIR GENEROUS CONTRIBUTION OF MANPOWER AND FACILITIES THIS STUDY COULD NOT HAVE BEEN MADE. ALSO COOPERATING IN VARIOUS ASPECTS OF THE WORK WERE THE CANADA DEPARTMENT OF AGRICULTURE, SCIENCE SERVICE, DIVISION OF FOREST BIOLOGY; QUEBEC DEPARTMENT OF LANDS AND FORESTS, BUREAU OF ENTOMOLOGY; AND U.S. DEPARTMENT OF AGRICULTURE, BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE.

of balsam fir was stripped off by the budworm larvae. The infestation had completely died out in this area by 1950.

Data on the effects of spruce budworm defoliation were obtained in two ways:

- From detailed measurements and observations of 23 permanent 1/5-acre sample plots established in 1948 on a 90-acre tract on Lake Larouche that was hit throughout by a very heavy epidemic. This was a rather intensive study of several thousand fir trees on one area.

- From records of mortality in 100-tree samples and observations of individual tree growth in a series of widely scattered stands within a 30-mile radius of Forbes Depot. In these stands the severity of budworm attack varied somewhat.

BUILD-UP OF FIR MORTALITY

In The Overstory

First mortality due to the budworm was recorded in 1948. Before that, even though trees had been infested in 1944--and possibly the previous year--only an occasional dead tree could be found that could be considered a victim

Table 1.--Development of balsam fir mortality after spruce budworm attack, 1948-52

(Trees 3.6 inches d.b.h. and up)

Location[1]	1948	1949	1950	1951	1952
	Percent	Percent	Percent	Percent	Percent
Lake Larouche	8	17	48	70	79
Windfall Road	—	15	20	28	33
Forbes Depot	--	4	17	17	26
O'Connell's Lodge	--	7	14	30	33
Wagoose Road	--	16	22	42	45
Barriere Road	—	18	26	47	--
Camatose Lake	—	14	24	38	50
Moose Lake Road	—	58	66	73	78
Catfish Depot	—	—	—	67	—

[1]All locations except Lake Larouche represent a grouping of 2 or more 100-tree samples taken within 5 miles of each other.

of the budworm. Mortality of trees 3.6 inches d.b.h. and larger on the heavily infested Lake Larouche area was 8 percent in 1948. The following year mortality more than doubled, to 17 percent; and from then on it climbed steadily to a high of 79 percent in 1952, the last year of observation (table 1).

First records on the 100-tree samples were not taken until 1949. At that time losses to fir in the 4-inch class and larger averaged 19 percent. The increase has been about 10 percent a year since then. By 1950 most stands had sustained at least 30 percent mortality, with extremes in individual samples ranging from 0 to 88 percent. By 1951 the average mortality was 40 percent; by 1952 it was 50 percent.

Of particular interest to the forest owner in Maine is the trend of mortality in the 6-inch class and larger, since these size classes constitute the operable growing stock of fir. There was no difference between death rates of the 4- and 5-inch fir and those in the 6- through 8-inch

Table 2.--Mortality of balsam fir after spruce budworm attack, by diameter classes, 1949-52

(Basis: Data from 25 100-tree samples)

D.b.h. class (inches)	1949	1950	1951	1952
	Percent	Percent	Percent	Percent
4 to 5	21	29	38	42
6 to 8	20	29	42	41
9+	24	38	51	61

classes (table 2). From 9 inches on, however, mortality averaged about 10 percent higher each year than for the trees below 9 inches.

In The Understory

In the 1- to 3-inch classes, trees that were killed by the budworm could not be distinguished from those that

died as a result of competition and the natural thinning process. In 1949, 33 percent of these small fir trees were dead on the Lake Larouche plots, and 30 percent in the combined 100-tree samples. This mortality was considerably higher than that of trees 3.6 inches d.b.h. and larger. By 1952 losses in trees less than 3.6 inches were 75 percent on the Lake Larouche tract and 52 percent in the other stands.

Data available from other studies indicate that under average stocking conditions in spruce-fir stands, between 5 and 10 percent of the small fir trees die yearly as a result of competition. There is little doubt that the death of many of these trees is hastened by partial defoliation. The net effect of the spruce budworm upon this segment of the stand could not be determined reliably in this study.

EFFECT OF TREE AND CROWN CONDITION ON MORTALITY

When the plots were established on the Lake Larouche area in 1948, 89 balsam fir trees differing in size class and crown condition were selected for individual study. It was hoped that this more detailed tree study would provide a key to some of the factors that influence mortality. For each tree the following data were recorded:

Vigor--As estimated by eye.

Crown class--Dominant, intermediate, or overtopped.

Crown ratio--Proportion of stem having live crown.

D.b.h.--To the nearest 1/10 inch.

Degree of defoliation--Light, medium, or heavy.

The trees were examined in 1952 to determine mortality and condition of survivors. Records for these trees are summarized in table 3.

Vigor was judged by density, character, and color of foliage, length of shoot growth, condition of the bark, and general appearance of the crown. It was thought that vigor might be one of the elements of tree condition associated with resistance to killing by defoliation. The limited data obtained fail to support this theory.

Dominant and intermediate trees sustained heavier losses than the overtopped trees. It should be pointed out that "overtopped" does not mean the same as "suppressed"; a

Table 3.--Summary of survival and mortality among sample fir trees on Lake Larouche experimental area

Tree and crown characteristics in 1948	Trees living in 1952	Trees dead in 1952	
	Number	Number	Percent
Vigor class:			
I	8	25	76
II	11	25	69
III	5	15	75
Crown class:			
Dominant	2	9	82
Intermediate	7	32	82
Overtopped	15	24	62
Crown ratio:			
.1 to .3	1	15	94
.4 to .6	21	44	68
.7 to .9	2	6	75
Degree of defoliation:			
Heavy	5	42	89
Medium	14	23	62
Light	5	0	0

fir may be overtopped but still not necessarily suppressed because it can grow satisfactorily in the understory. It is believed that the dominants and intermediates, having their crowns in the sunlight, or at least partly so, and having denser foliage and hence more food, can support heavier budworm populations than overtopped trees.

This is confirmed by the fact that 68 percent of all dominants and intermediates were classed as having "heavy" defoliation in 1948, as compared to 33 percent of the overtopped trees. The inference is that the taller trees are not necessarily less able to survive defoliation, but are more vulnerable to it because of the well-known tendency of the insect to feed and lay its eggs in the light.

Degree of defoliation was determined by close examination of the twigs through binoculars. No very accurate quantitative measure of defoliation was feasible without spending a great deal of time on it; so an arbitrary scheme was decided upon. If more than an estimated two-thirds of all foliage had been destroyed, damage was classed as heavy;

between one-third and two-thirds, medium; and less than one-third, light.

Degree of defoliation in 1948 has proved to be a key to survival and mortality of the sample trees. Of the trees that were classed in 1948 as having heavy damage, 89 percent died; but only 55 percent of those classed as medium or light were killed. The few fir trees (5 out of 89) that had only light damage in 1948 have all survived. Four of these were overtopped and one was intermediate.

Crown ratio is an expression of quantity of foliage just as vigor is an expression of the quality. It appears to be more closely associated with mortality than is vigor. Thus of the 16 trees having a crown ratio of between 0.1 and 0.3 at the time of first measurement, only 1 survived. In contrast, the trees with 0.4 crown ratio or better have averaged 32 percent survival. The apparently contradictory figures in the 0.7 to 1.0 crown ratio group are probably due to the smallness of the sample--only 8 trees.

This effect is due partly to the greater physiological vigor of the fast-growing, long-crowned trees. Also, their greater supply of needles and buds would enable them to withstand an intensity of attack that would completely strip and kill a short-crowned tree. It has already been mentioned that the sheltered position of overtopped trees was probably responsible for their higher rate of survival. Similarly, trees with long crowns would benefit by the fact that lower branches, being in the shade, were not so heavily fed upon by the light-preferring budworm larvae. Hence such trees, even though badly defoliated in the tops, would still have foliage in the lower branches to provide food for continued growth.

EFFECT OF SITE AND STAND ON MORTALITY

Observations on mortality during the first years of this study indicated that losses were somewhat heavier on wet sites than on well-drained sites. In 1952 special note was made of the drainage conditions in each stand that contained 100-tree samples. These stands were then grouped into two classes: well-drained and imperfectly drained. Average mortality was 33 percent on the well-drained sites, as compared to 54 percent on poorly drained sites. But it was also apparent that in areas where mortality was uniformly heavy, such as the Moose Lake and Larouche sections,

drainage had less influence. For example, the highest mortality found on any sample was the 89 percent recorded on a well-drained slope in the Moose Lake area.

Similarly, an attempt was made to classify stands into young-thrifty and mature categories, since the more vigorous stands might show a higher survival. No consistent relationship was found, although interactions of drainage and type may have obscured the influence of age and vigor of stand. Here too it appeared that where heavy local infestation centers occurred, mortality was very high regardless of the age or prior vigor of the stand.

The effect of hardwood overstory was examined, but no conclusions could be drawn. Only a few of the stands could be classified definitely as having or not having a sheltering canopy of hardwoods above the fir. In most cases the hardwoods were patchy, with a scattering of softwoods intermixed. Recent and extensive mortality of white birch also complicated the picture. There was a strong indication, however, that mortality of fir is lower in mixedwood stands than in softwood stands. This theory is supported by the good survival of overtopped trees as compared with dominants and intermediates.

EFFECT OF DEFOLIATION ON DIAMETER GROWTH

Examination of the stump or an increment core of almost any large fir in the spruce-fir region of Maine will reveal a typical "budworm pattern." This is a series of narrow growth rings, usually 5 to 7, beginning about 1920. It is well established that this period of reduced growth was a result of defoliation by the budworm during its previous outbreak.

To determine the effects on growth of defoliation during the current epidemic, borings were made on more than 100 fir trees, ranging from 4 to 11 inches d.b.h., in the Forbes Depot study area. The cores were examined under a binocular microscope and the following data were recorded for each.

- Diameter growth, to the nearest 1/100 inch, for the 5-year period before the start of depressed growth.
- Diameter growth during growth depression.
- Year of first growth depression.

- Year of greatest growth depression (i.e., year of narrowest ring).
- Duration of depressed growth period.

The sample trees were selected at random in about 20 different stands that had suffered severe defoliation. The trees included 14 that had died during recent months as well as a number with healthy, vigorous crowns that seemed to have completely recovered or in fact that gave no immediate evidence of ever having been defoliated at all.

The cores from all trees, regardless of condition, showed a depression of diameter increment. However, the time that this occurred, its duration, and the year of maximum depression varied considerably.

Amount Of Growth Depression

For all sample trees, the average period of depressed growth was $4\frac{1}{2}$ years at the time of the last measurement. If the rate of growth of the previous 5 years had been maintained, the average diameter increment of the sample trees for that $4\frac{1}{2}$-year period would have been 0.53 inch. The actual growth was only 0.16 inch, a loss of 0.37 inch.

This trend was substantiated by the growth of the 24 surviving fir sample trees on plots in the Lake Larouche area. In 1948 these trees were measured to the nearest 1/10 inch and the point of measurement was marked. In 1952, average 4-year diameter growth was 0.12 inch, corresponding rather closely to the 0.16 inch in $4\frac{1}{2}$ years for the sample trees mentioned in the previous paragraph. Five of the 24 trees did not increase in diameter at all.

An interesting contrast is found in the growth of 30 black spruce sample trees in the same area. Although black spruce is normally much slower growing than fir, the average increase in diameter of the sample trees was 0.32 inch. Five white spruce trees included in the sample averaged 0.44 inch in the same 4-year period. Neither black nor white spruce trees were defoliated by the budworm as severely as fir.

Effect Of Growth Rate Before Defoliation

Average 5-year diameter increments of all sample trees before the period of growth depression and during depression were summarized by 0.20-inch growth classes before

depression. Average "before" growth was plotted over "during" growth for each class. Values read from a balanced curve drawn through these points are shown in table 4.

As expected, the slowest growth observed during the depression period was for those fir trees that had been growing slowest before the budworm epidemic. For example, trees that had made only 0.20 inch diameter growth in the 5 years before budworm attack grew at the rate of 0.08 inch after the effects of defoliation became evident. By contrast, for fir that had been putting on 1 inch in diameter in 5 years, the rate was 0.27 inch.

Table 4.--Diameter growth of sample fir trees before and during period of depressed growth due to defoliation by spruce budworm

Average 5-year diameter growth		Decrease in growth	
Before depression*	During depression		
Inches	Inches	Inches	Percent
0.20	0.08	0.12	60
.40	.14	.26	65
.60	.19	.41	68
.80	.23	.57	71
1.00	.27	.73	73
1.20	.30	.90	75

*Sample trees grouped into 0.20-inch growth classes.

As will be noted, there was a tendency for the proportional difference between fast- and slow-growing trees to narrow as the growth rate was reduced. This is shown by the percentage figures in the last column in table 4. Thus the decrease for the slowest growing trees was 60 percent of previous growth, but for those that had been adding 1 inch in diameter in 5 years it was 73 percent.

Time Pattern Of Defoliation Effects

In spite of widespread infestation and defoliation from 1944 (and possibly from 1943) on, no reduction in ring growth occurred until 1946, and then only 5 percent of the trees were affected. The following year 29 percent of the

trees underwent the first reduction in growth. Of particular interest is the fact that as late as the end of 1949 some 20 percent of the trees examined had shown no depression of ring growth. Table 5 shows the percentage distribution, by years, of the first narrow growth ring and the narrowest growth ring.

As shown in table 5, there was more consistency among the sample trees with respect to the year of greatest growth depression. In 92 percent of the cases this occurred in 1950 or 1951. It should be mentioned that the narrowest

Table 5.--Time pattern of defoliation effects on sample fir trees

Year	First effect of defoliation shown by growth rings	Greatest depression of growth occurred
	Percent of trees	Percent of trees
1946	5	0
1947	29	0
1948	27	0
1949	19	3
1950	18	57
1951	2	35
1952	0	5
	100	100

ring was not always conspicuously so. In fact, in a few cases there were two of equal width, as nearly as could be measured (i.e., to the nearest 1/100 inch). In such cases the later year was recorded.

The spruce budworm epidemic in this district declined sharply and suddenly in 1950. In that year the inspection was made in October. There was little evidence that there had been many budworms during the previous spring and summer. Few pupal cases or egg masses were found, and local woodsmen reported seeing few larvae in the forest. These observations, plus the absence of any appreciable defoliation, were fairly conclusive evidence that the epidemic had passed. This was confirmed in 1951 when examination of many trees showed no discernible new defoliation. In fact, most trees

had 2 years' foliage that was virtually undisturbed, and 1 year's foliage (1949) that was only partly damaged. The course of the epidemic ran from 1944 to 1949, with the heaviest feeding from 1945 to 1948.

In spite of the fact that in 1950 foliage was nearly intact, and in 1951 completely so, ring growth reached a minimum on nearly all sample trees in one or the other of those 2 years. Furthermore, in very few cases--less than 10 percent--had the period of growth depression ended by 1952, although recovery with respect to renewal of needle and twig growth had started on 95 percent of the trees. While no observations on diameter growth were made after 1952, it seems safe to say that most trees did not regain their former growth rate in 1953.

Thus there was a lag of 3 to 6 years between the first severe defoliation and the slow-down in diameter growth. Similarly, there was a lag in response at the end of the epidemic. The defoliation ended in 1949 and foliage development was unimpaired from then on. However, the period of depressed growth continued for at least 3 years, and probably more, although this cannot be stated positively since no examinations were made after 1952.[3]

It seems impossible that any substantial amount of food could have been synthesized by new foliage after 1945. Examination of the twigs of many fir trees during the 8 years of this study showed that from 1945 to 1948 virtually no new needles were put out by balsam fir trees in this region. New buds were formed but a high percentage of them were mined and destroyed before they had a chance to develop.

The continued diameter growth on most surviving trees through 1946 and on one-fifth of them as late as 1950, was probably due to two factors. First, photosynthesis undoubtedly continued in the older foliage. This may have proceeded at a somewhat higher than normal rate for old needles because there was no shading effect by new needles. Since fir needles have an average life of 5 to 7 years, some foliage would have been left as late as 1950, provided the budworm did not consume it. The budworm, however, is known to prefer new needles, feeding upon the older ones only when forced to

[3]TO WHAT EXTENT DIAMETER GROWTH WILL RETURN TO ITS PRE-BUDWORM RATE IS PROBLEMATICAL. EXAMINATION OF THE GROWTH PATTERN OF MANY FIR TREES THAT SURVIVED THE 1909-19 OUTBREAK HAS REVEALED THAT THERE WAS USUALLY A SERIES OF 6 NARROW RINGS, FOLLOWED BY GRADUALLY WIDENING RING GROWTH. IN MOST CASES, HOWEVER, RECOVERY WAS NEVER COMPLETE. DIAMETER GROWTH COMMONLY FAILED TO ATTAIN THE RATE SHOWN JUST BEFORE THE EPIDEMIC STARTED.

by population pressure. Observations of surviving fir trees through 1950 confirmed that old needles did remain on the twigs up to that time, although their quantity in many cases was small and they persisted principally on the lower half of the crown.

The other factor that would help account for continued diameter growth is the availability of stored food reserves in the tree. The exhaustion of food reserves, plus the gradually weakened photosynthetic power of the older needles, probably combined finally to reduce diameter growth.

Growth Pattern

Above Breast Height

All growth data on sample trees were taken at breast height. Therefore, it seemed advisable to make a few supplementary borings at higher points on the tree trunk to determine if the growth pattern paralleled that at breast height. On five sample trees selected at random, increment borings were made at four points on the trunk: (1) At breast height; (2) halfway between breast height and the bottom of the live crown; (3) at the bottom of the live crown; and (4) at the middle of the live crown.

Examination of the cores showed that the effect of defoliation on diameter growth was about the same at all positions. Neither the first year of growth depression nor the year of the narrowest ring varied appreciably or consistently. Insofar as rate of growth was concerned, some minor fluctuations were noted but with one exception these seemed to be strictly random. Only the cores taken in the middle of the live crown were consistently different. At this point increment rate was 30 percent higher than the average for the other three positions prior to growth depression, and 58 percent higher during the depression period.

These data, however, are somewhat at variance with observations by entomologists in Maine during the 1909-19 outbreak and in Ontario during the more recent epidemic. In those studies an earlier reduction in radial increment was found in the upper part of the trunk than at breast height. The difference may be due to too few measurements in this study, or to different conditions. For this report it will be assumed that conclusions drawn from measurements at breast height are valid as applied to the effect of defoliation upon total cubic-foot growth of the entire tree.

PROBABLE FUTURE MORTALITY

The data presented in this report cover the period 1945-52. Although the epidemic ended in 1949, mortality continued through 1952. The question may well be asked, What of the future? Will the fir continue to die from the effects of defoliation for another 5 years or more? And if it does continue to die, what will be left for a future crop?

To provide a basis for predicting the future of balsam fir in this area, the surviving sample trees on the Lake Larouche plots were examined in 1951 in terms of probable survival. This classification was as follows:

Class 1.--Trees putting on substantial terminal and lateral twig growth, and whose crowns had a substantial amount of new foliage. All danger of mortality was considered past.

Class 2.--Trees whose crowns had not fully recovered from defoliation but were producing a fair amount of new needles. These were given a 50-50 chance for survival.

Class 3.--Trees apparently dying. New buds were formed but little new foliage was developed. Tops were usually dead more than halfway down. One hundred percent mortality is expected within 5 years.

In 1952 these trees were examined and re-tallied on the same basis, and new mortality was recorded. During the period 1951-52, 7 of the surviving 31 sample trees died, all of them Class 3. There were 12 other Class 3 trees still living in 1952, at which time 4 had improved enough to be put in Class 2. Of the 8 trees originally in Class 2, half were still in Class 2 and the other half in Class 3 by 1952. All 4 trees originally in Class 1 were still in that class in 1952.

Of course, these class definitions are arbitrary. It is quite likely that not all Class 1 trees will survive, and that not all Class 3 trees will die. However, for the purposes of a rough prognosis of future mortality this classification seemed adequate. Accordingly in 1952 an effort was made to estimate probable future mortality in this region. All surviving fir trees in the 4-inch class and larger that were recorded on all sample locations were classified this way. The results are shown in table 6.

If it is assumed that all Class 3 trees and half those in Class 2 will die within 5 years as a result of de-

foliation, the probable mortality can be estimated. This has been done in table 6. Thus it may be expected that in this region as a whole 47 percent of the fir now surviving will die. This means that total mortality attributable to the budworm of trees in the 4-inch class and larger may amount to 75 percent.

Table 6.--Distribution of sample trees by survival classes

(Surviving fir trees 3.6 inches d.b.h. and up, October 1952)

Location	Class 1	Class 2	Class 3	Probable future mortality
	Percent	Percent	Percent	Percent
Windfall Road	55	26	19	32
Forbes Depot	43	34	23	40
O'Connell's Lodge	41	42	17	38
Wagoose Road	54	24	22	34
Camatose Lake	18	33	49	65
Moose Lake Road	15	44	41	63
Lake Larouche	22	35	43	60
All locations	36	34	30	47

What does this leave for the future? The average stand examined originally supported 260 fir trees per acre 3.6 inches d.b.h. and larger, representing 7.5 cords per acre. Applying the mortality figures from the previous paragraph, this would leave an average per-acre nucleus of 65 trees. The per-acre volume will be low because most of the trees above 8 inches will probably die.

An additional note of warning must be sounded. A very high percentage of surviving fir have dead tops resulting from heavy and repeated defoliation of the upper branches. This is true of about 70 percent of the dominant trees and 50 percent of the intermediate and overtopped trees. The killed portion averages 6 to 8 feet in length, but in many cases--particularly in dominant trees--occurs much farther down the stem. While new leaders are quickly established from one of the top-most lateral shoots, decay may enter at the base of the dead portion of the trunk. Losses caused by the so-called "top rot" of fir are well known to most people who have worked with this species. Foresters and woods managers should be aware of the possibility of widespread

decay among the dead-topped fir that survive defoliation by the budworm. Such fir may require cutting within 10 years if additional heavy losses are to be avoided.

CONCLUSIONS AND SUMMARY

Because this investigation was carried out in southwestern Quebec, a few limitations imposed by differences in forest conditions must be kept in mind when applying results to Maine and New Hampshire.

Other studies have shown that the most intense budworm epidemics build up in regions of extensive, continuous stands of spruce and fir. On this basis, the distribution of forest types in the Quebec study area makes it relatively unfavorable for the build-up of a uniformly heavy epidemic over hundreds of square miles. Large areas burned over in the past now support mixed stands of paper birch, red maple, and various softwoods. A great deal of the pure softwood land is either black spruce or jack pine, neither of which is attacked to any extent by the budworm except when they occur in stands primarily made up of fir.

This situation is different from that encountered in much of northern New England. While it is true that mixed stands similar to those studied are common, extensive forests of softwood type running heavily to fir are also characteristic of most of the region. It is possible, therefore, that because of more favorable conditions for a build-up of the budworm, the epidemic in this area could be more devastating than that in southwestern Quebec. If this is the case, then the mortality and growth-reduction data presented for Quebec may be conservative when applied to an all-out budworm attack here. Similarly, the time lag between first defoliation and mortality, representing time available for salvage, may be shorter.

With this in mind, the following represent the major points to be gained from this study.

In the area studied there was a 5-year period from the first severe defoliation (1944) until trees began to die in substantial numbers (1949). The wood of fir trees will probably be usable for pulp for a year after death of the tree. Therefore, to avoid serious losses of fir, salvage operations on high-hazard areas should be completed within 6 years after the first heavy infestation.

Mortality varied considerably from place to place within the approximately 1,000 square miles of the study

area. The range of about 25 to 80 percent in fir losses is thought to reflect local differences in intensity of attack. It was the opinion of a Canadian entomologist who assisted in the inspection of the study area on one occasion that the infestation in this region developed a series of small centers, and that high mortality was associated with proximity to these centers. It seems possible that the broken-up nature of the forest may have been responsible for the development of this patchwork of infestation centers.

Tree survival does not appear to be related to vigor, as had been expected. Rather, length of crown seems to be more directly associated with ability of trees to recover from defoliation. In the tree diameter classes above 3 inches, overtopped (not suppressed) trees apparently received less severe defoliation because of their sheltered position and showed a much higher survival rate than either dominants or intermediates.

Some trees had sustained a relatively moderate amount of defoliation by the fifth year of the epidemic as compared to others of the same size, form, and condition immediately surrounding them. These trees ultimately suffered only 55 percent mortality as compared to 89 percent for those that had been heavily defoliated. No explanation is offered for this difference in defoliation of apparently similar trees in the same stand. It is merely pointed out that under the definition of "heavy defoliation" used in this study, nearly all balsam fir that had lost more than two-thirds of their needles by the fifth year ultimately died.

This study did not permit adequate evaluation of the effect of forest type and site quality on mortality. There was a suggestion that mortality was about 20 percent higher on poorly drained than on well-drained sites. Similarly, losses were somewhat less under a sheltering canopy of hardwoods than in pure softwood types. However, because of the effect of local infestation centers, and the fact that pure softwoods were generally found on poorly drained sites, no definite conclusions can be drawn.

In addition to the complete loss of fir killed by the budworm, there will be a considerable loss in wood production due to slowing down of growth on surviving fir trees. This will probably amount to about 75 percent of the mean annual increment over a 6- or 7-year period. A crude picture of what this could amount to in Maine can be obtained by making a few assumptions. If half the 2 million acres of operable spruce-fir forest in this State were subjected to an infestation that killed 50 percent of the fir, and if the

pre-budworm growth of this surviving fir had been 10 cubic feet per acre per year, then the hypothetical losses over a 6-year period would amount to 75 percent of 6 years times 10 cubic feet. On a million acres of forest this would come to 42 million cubic feet, representing about 400,000 cords.

There is a lag between the initial defoliation of a fir tree and the first reduction in diameter growth. Another lag of at least 3 years occurs between the time of crown recovery after the epidemic, and a response to this recovery in terms of diameter growth. These lags are thought to be related to continued photosynthesis in the old needles, particularly in the lower part of the crown, and to the utilization and ultimate exhaustion of stored food reserves.

From the condition of surviving fir trees in 1952 it is estimated that nearly half of them will eventually die as a result of defoliation. This would bring final mortality for this region to about 75 percent. The surviving 25 percent of the original growing stock will constitute a very small volume, but in the mixed stands of the region will be the nucleus for a light but operable cut over much of the area in 15 to 20 years.

However, more than half the surviving fir in the study area had dead tops as a result of repeated defoliation, and further substantial losses in volume from top rot are to be expected in the future.

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